Docket No.: FOM-141.01

METHODS AND SYSTEMS HAVING MULTIPLE COOPERATING TRANSFORMERS

CROSS REFERENCE TO RELATED APPLICATIONS

[0001] This Application is related to and claims the benefit of Provisional Application Serial No. 60/459,118, filed on March 31, 2003, and entitled "Voltage Regulator".

BACKGROUND

(1) Field

[0002] The disclosed methods and systems relate generally to power systems, and more particularly to multiple transformer configurations.

(2) Description of Relevant Art

[0003] A common problem in situations involving power system transformer failure is that there is typically a short time lag between the time the main transformer has ceased operation, and the time the back-up transformer, if one is installed, begins operations and allows the power system to resume regular operation. Such a time lag, even if relatively short, and the resultant power interruption to power-consuming devices connected to the power system via the failed transformer could cause sensitive power devices to shut down, thereby resulting in potentially serious economic damage to consumers affected by the power disruption and the ensuing shut down of economically critical power applications. For instance, electrically powered chemical refineries, paper mills, and other similar operations, could suffer economic harm by a power disruption caused by a failed transformer. Additionally, it often becomes necessary to take a transformer off-line for necessary maintenance work. Under these circumstances, a power disruption to consumers, even if a back-up transformer is ready to assume operation, is often inevitable, and could also result in economic harm.

[0004] One possible way to address these types of power disruptions is to connect the power-consuming devices to two or more independent power sources. However, such a solution may not be feasible due to expensive overhead necessitated by the connection of two or more power sources, and the accompanying apparatus (e.g., power lines, transformers, etc.). Moreover, such a solution also entails considerable power waste since more power is available to the power-consuming devices than is generally required. Another solution then is to connect two, or more, transformers to the power source supplying power to the power-consuming devices, so that the two, or more, transformers can operate in tandem and thus provide back-up or redundancy to the power system. Although this solution appears to be satisfactory and simple, tandem operation of two or more transformer has been unsatisfactory due to the tendency of multiple transformers used conjunctively to compete with each other for the power supplied by the power source. Consequently, competing transformers cause the power system to become unstable as the voltage levels at the output of the transformers feeding the power consuming devices fluctuate.

SUMMARY

[0005] Disclosed are methods and systems that include a power supply system comprising a power source having a first voltage signal having a first frequency; at least one power-consuming load; a first transformer set comprising a delta-delta transformer, and a first voltage controller electrically coupled in series to the delta-delta transformer, the first transformer set having an input and an output, the input of said first transformer set is electrically coupled to the power source to receive the first voltage signal and produce a second voltage signal having a second frequency, and the output of said first transformer set is coupled to the at least one power-consuming load; and a second transformer set comprising a wye-delta transformer, and a second voltage controller electrically coupled in series to the wye-delta transformer, the second transformer set having an input and an output, the input of the second transformer set is electrically coupled to the power source to receive the first voltage signal, the output of the second transformer set is coupled to the at least one power-consuming load, and the wye-delta transformer causes a phase shift to the first frequency of the first voltage signal such that the

second transformer set produces a third voltage signal having a third frequency, the third frequency being out of phase with respect to the second frequency; the second transformer set and the first transformer set are coupled in an electrical parallel configuration such that the second voltage signal and the third voltage signal combine to produce a fourth voltage signal having a fourth frequency at the at least one power-consuming load.

[0006] The first transformer set of the power supply system can further comprise a first switch for electrically disconnecting the power source from the at least one power consuming load through the first transformer set, and the second transformer set can further comprise a second switch for electrically disconnecting the power source from the at least one power consuming load through the second transformer set.

[0007] The first voltage controller of the first transformer set of the power supply system can cause the second voltage signal to be half-wave rectified, and the second voltage controller of the second transformer set causes said third voltage signal to be half-wave rectified.

[0008] Also disclosed are methods and systems that include a power supply system comprising a power source having a first voltage signal having a first frequency; at least one power-consuming load device; a first transformer group comprising a first delta-delta transformer electrically coupled in series to a first voltage controller, and a first wye-delta transformer electrically coupled in series to a second voltage controller, the first delta-delta transformer and the first voltage controller connected in an electrical parallel configuration to the first wye-delta transformer and the second voltage controller, the first transformer group has an input and output, the input of the first transformer group is electrically coupled to the power source and the output of the first transformer group is electrically coupled to the at least one power-consuming load, the first transformer group receives the first voltage signal and produces a second voltage signal having a second frequency; and a second transformer group comprising a second delta-delta transformer electrically coupled in series to a third voltage controller, and a second wye-delta transformer electrically coupled in series to a fourth voltage controller, the second delta-delta transformer and said third voltage controller connected in an electrical parallel configuration to the second wye-delta transformer and the fourth voltage controller, the second

transformer group has an input and output, the input of said second transformer group is coupled to the power source and the output of the second transformer group is electrically coupled to the at least one power-consuming load, and the second transformer group produces a third voltage signal having a third frequency based on the first voltage signal, and the second transformer group is further electrically coupled in series to a phase-shifter that causes the third frequency to be phase-shifted with respect to the second frequency; the first transformer group is connected in an electrical parallel configuration to the second transformer group and the phase-shifter such that the second voltage signal and the third voltage signal combine to produce a fourth voltage signal having a fourth frequency.

[0009] The first transformer group of the further disclosed power system further comprises a first switch for electrically disconnecting the power source from the at least one power consuming load through the first transformer group, and the second transformer group further comprises a second switch for electrically disconnecting the power source from the at least one power consuming load through the second transformer group.

[0010] The first voltage controller and the second voltage controller of the first transformer group of the further disclosed power supply system cause the second voltage signal to be half-wave rectified, and the third voltage controller and the fourth voltage controller of the second transformer group cause the third voltage signal to be half-wave rectified.

[0011] Other objects and advantages will become apparent hereinafter in view of the specification and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] **FIG. 1** is a schematic diagram of one embodiment of a power system with multiple redundant cooperating transformers disclosed herein;

FIG. 2 is a schematic diagram showing a more detailed illustration of the system according to **FIG. 1**;

FIGS. 3-7 are schematic diagrams showing further details of the system according to **FIGS. 1** and **2**; and

FIG. 8 is a schematic diagram showing an exemplary Excitation Drive system retrofit application using the system according to **FIG. 1**;

FIG. 9 is a schematic diagram of a second embodiment of a power system with a multiple redundant cooperating transformers described herein.

DESCRIPTION

[0013] To provide an overall understanding, certain illustrative embodiments will now be described; however, it will be understood by one of ordinary skill in the art that the systems and methods described herein can be adapted and modified to provide systems and methods for other suitable applications and that other additions and modifications can be made without departing from the scope of the systems and methods described herein.

[0014] Unless otherwise specified, the illustrated embodiments can be understood as providing exemplary features of varying detail of certain embodiments, and therefore, unless otherwise specified, features, components, modules, and/or aspects of the illustrations can be otherwise combined, separated, interchanged, and/or rearranged without departing from the disclosed systems or methods. Additionally, the shapes, sizes, and brands of components are also exemplary and unless otherwise specified, can be altered without affecting the disclosed systems or methods. Accordingly, although the methods and systems described herein may represent certain components of the Triconex, Eurotherm, and/or other component manufacturers, such components are merely illustrative and other components that provide similar features or that can be modified to provide similar features, can be used.

[0015] The disclosed methods and systems relate to multiple transformer arrangements that can be used with power systems, although the methods and systems may be applied to systems other than power systems. The methods and systems can be employed in one or more embodiments that can include, for example, one or more embodiments that may provide for alternating and/or parallel operation.

[0016] **FIG. 1** shows an embodiment of a power system **100** for driving an electromechanical device, in this case a brushless exciter **102**. Brushless exciter **102** can be one of the many commercially available brushless exciters, such as those manufactured by the Electric Machinery Company or by Toshiba, and may be used to create rotational torque needed to operate an electromechanical device (such as a domestic or industrial machine), or to create a magnetic field in a generator necessary for the generation of electricity. It will be appreciated that the use of a brushless exciter with the system of **FIG. 1** is for demonstration purposes, and that other power devices may be used instead of the brushless exciter shown. Moreover, although only one load device is shown connected, a large number of load devices may be connected to power system **100**.

[0017] As also seen in **FIG. 1**, input power source **104** is connected to the input of a first transformer **110**, labeled as Transformer A, and a second transformer **120**, labeled as Transformer B. Although depicted as a 3-phase AC generator, it can be understood that input power source **104** may be the contact point between the transmission lines connecting a general power system to the system **100**. As can be seen, first and second transformers **110** and **120** are connected in a parallel configuration, and accordingly both first and second transformers **110** and **120** may individually and independently handle and assume the entire power provided by input source **104** so that in the event that one of first and second transformer **110** and **120** fails, the other transformer can handle the additional power, previously handled by the failed transformer.

[0018] As shown, first transformer **110** is a delta-delta transformer that takes as input the 3-phase input voltage provided by input power source **104**, and outputs a 3-phase output voltage. The output voltage of a delta-delta transformer depends on the ratio between the number of wire turns on the primary winding **112** (i.e., on the first delta of first transformer **110**), and the number of turns on the secondary winding **114** (i.e., on the second delta of first transformer **110**). The output of first transformer **110** is coupled to the input of a first voltage controller **116**, which may one of many commercially available voltage controllers, or drivers, including, for example, the Eurotherm 590+ DRV DC driver. Among other things, first voltage controller **116** may, if desired, provides controlled DC at the output of the controller by directing the AC voltage

presented as input to the controller to a DC rectifying bridge. Voltage controller **116** may also provide Proportional-Integral-Derivative (PID) control capabilities, and other control features that facilitate power control, and/or the elimination of spurious fluctuations and oscillations in the amplitude and frequency of the transformer produced voltage being controlled by the voltage controller to provide the target electromechanical device (in this case brushless exciter **102**) a voltage signal. For example, the PID functionality of such a voltage controller could be employed to change the output current of the respective transformer based on a current setpoint. The current setpoint can be based on the output of a PID controller that can measure and/or accept as input the generator voltage and/or otherwise provide an output based on the generator voltage. The first voltage controller **116** may also be implemented using a general purpose CPU-based device, comprising memory elements and peripheral devices having receiving/transmitting functionality, and/or other circuitry needed for the operation of voltage controller **116** and the execution of any software thereon. When implemented as a general purpose CPU-based device, first voltage controller **116** would also require input power ports for receiving the power voltage that is to be controlled, and output power ports for providing the controlled (or regulated) output power voltage to load device **102**. As such, these input/output power ports, and an internal module or component that handles the power voltage received from first transformer **110** would have to have a power rating large enough to handle the large power levels delivered by input power source **104**. Optionally, to facilitate the operation of first voltage controller **116,** a first power conditioner **118** may be connected to power controller **116**. As is known in the art, power conditioners can be used to regulate, filter, and suppress noise in AC power. First power conditioner **118** may be one of many commercially available power conditioner, including, for example, the Constant Voltage Power Conditioner manufactured by Sola Hevi-Duty, or may also be implemented as a general purpose CPU-based device having the necessary memory elements, peripheral devices to enable receiving/transmitting functionality, and/or other circuitry for control of power conditioner, as well as input ports for receiving and handling the large input voltage power from input power source **104**, and output ports for directing control signals to first voltage controller **116**. These control signals enable first voltage controller **116** to adjust its operation to

produce the rectified voltage provided to load device **102**. For the purposes of the present discussion and for ease of reference, a transformer coupled to a voltage controller and/or power conditioner will be collectively referred to as a transformer set. Accordingly, as shown in **FIG. 1**, first transformer set **119** comprises delta-delta transformer **110**, first voltage controller **116** and first power conditioner **118**.

[0019] Connected to the input of first transformer **110** and to the output of first voltage controller **116** are switches **130** and **134** respectively. When first transformer set **119** malfunctions or otherwise is taken off-line for regular maintenance work, switches **130** and **134** may be placed into their open position to electrically disconnect first transformer set **119**, and thereby allow maintenance personnel to repair, maintain, or replace any or all of the modules making up transformer set **119**.

[0020] Connected in parallel to first transformer set **119** is second transformer set **129**. Like first transformer set **119**, second transformer set **129** comprises a second transformer **120** whose input is coupled to input power source **104**, and whose output is connected in series to a second voltage controller **126**. Second power conditioner **128** is also connected to the input power source **104**, and upon processing of the 3-phase input power voltage it receives from input power source **104**, second power conditioner **128** sends control signals to second voltage controller **126**. Second voltage controller **126** uses the control signals it received from second power conditioner **128** to operate and process the transformed voltage power it receives from the output of second transformer **120**. In the embodiment of **FIG. 1**, second transformer **120**, labeled as Transformer B, is a wye-delta transformer. As will be appreciated by the person of ordinary skill, aside from transforming the voltage level of input power source **104** in accordance with the winding ratio of second transformer **120**, a wye-delta transformer also causes the output power voltage (i.e., at the delta winding **124** of the second transformer **120**) to be shifted by 30° with respect to the input power voltage received from input power source **104**. Thus, the second voltage controller **126** can produce a rectified output voltage similar to the rectified voltage power produced by first voltage controller **116**, except that the rectified voltage signal produced by second voltage controller **126** can be phase shifted, such as, for example, by 30°. Connected to the input of

second transformer **120** and to the output of second voltage controller **126** are switches **132** and **136** respectively. These switches are used to electrically disconnect transformer set **129** when the transformer set malfunctions or otherwise requires some maintenance work.

[0021] As shown by **FIG. 1**, first transformer **110** is a delta-delta transformer, and second transformer **120** is a wye-delta transformer. The use of "first" and "second" is merely for convenience purposes and is arbitrary.

[0022] In operation, input power source **104** presents a 3-phase voltage signal (shown in **FIG. 1** as signal **140**) to the delta-delta transformer **110** and the wye-delta transformer **120**. First transformer **110**, which has a winding ratio that produces the desired voltage level at the output of the transformer, transforms the voltage level of input power source **104** to a voltage needed for operation of the output device **102**. As was noted, a delta-delta transformer does not cause a phase shift in the resultant transformed output voltage signal relative to the input voltage. First voltage controller **116** receives the transformed output voltage produced by first transformer **110** and the control signals generated by first power conditioner **118**, and produces a half-rectified voltage signal, such as exemplary first signal **142** shown in **FIG. 1**. As exemplary first signal **142** shows, the output produced by power controller **116** includes the positive polarity portion of the output of the 3-phase voltage transformed by delta-delta transformer **110**, but does not include the negative polarity portion of the transformed voltage signal due to the rectifier circuitry of first voltage controller **116**. It will be understood that first voltage controller **116** may provide a fully rectified output signal, or may otherwise process the signal presented as input to it in other ways known in the art. As can be seen from the illustration of first signal **142**, showing the rectified shaded signal overlaid on the outlines of the 3-phase output signal produced by delta-delta transformer **110**, one cycle of the transformed output signal results in six cycles of the rectified signal **142**. Thus, for a 3-phase input power voltage having a frequency of 60 Hz (i.e., 60 cycles per second), the voltage controller **116** would produce a rectified voltage having a frequency of 360 Hz.

[0023] Similarly, voltage signal **140** is presented at the input to the wye-delta transformer **120**. Second transformer **120**, which may have the same winding ratio to produce the same

voltage level at the output of the transformer that was produced by the delta-delta transformer **110**, transforms the voltage level of input power source **104** to a desired voltage level. As was noted, a wye-delta transformer causes a phase shift of 30° in the resultant transformed output voltage relative to the input voltage. The transformed output voltage produced by second transformer **120** is presented as input to second voltage controller **126**, which further uses the output signals generated by second power conditioner **128** to produce a half-rectified voltage signal, such as exemplary second signal **144** shown in **FIG. 1**. As exemplary second signal **144** shows, the output produced by second voltage controller **126** includes the portion of the 3-phase voltage output of the wye-delta transformer **120** having a positive polarity, but does not include the negative polarity portion due to the rectifier circuitry of second voltage controller **126**. Again, it will be understood that second voltage controller **126** may provide a fully rectified output signal, or may otherwise process the voltage signal it receives as input in other ways known in the art. As can be seen from the illustration of second signal **144**, showing the half-rectified shaded signal overlaid on the outlines of the 3-phase wye-delta transformer output signal, one cycle of the transformer's 3-phase output signal corresponds to six cycles of the signal produced by second voltage controller **126**. As can further be seen by comparing first signal **142** (the signal produced by voltage controller **116**) to second signal **144**, second voltage signal **144** is shifted by 30° with respect to voltage signal **142**, but is otherwise the same. As can further be seen, second voltage signal **144** comprises six voltage cycles for every one cycle of any one phase of the 3-phase AC voltage produced by wye-delta transformer **120**. Thus, for a 3-phase input power voltage having a frequency of 60 Hz (i.e., 60 cycles per second), second voltage controller **126** produces a voltage signal having a frequency of 360 Hz.

[0024] In the **FIG. 1** embodiment, first and second signals **142** and **144** are thus presented to device **102** as two signals having substantially the same amplitude and signal shape, but with one signal shifted by 30° with respect to the other. As first and second signals **142** and **144** are not congruent, the two signals thus combine constructively to form resultant voltage signal **146**. As first and second signal **142** and **144** each comprise six cycles for every one cycle of any one of the phases of the input 3-phase AC voltage presented by the power source **104**, or by the outputs

of transformers **110** and/or **120**, signal **146** thus has twelve cycles for every cycle of the original voltage signal provided by input power source **104**. Consequently, a 60 Hz 3-phase AC voltage signal presented at the input of the system **100** would result in a single-phase 720 Hz signal (60 cycles x 12 peaks/cycle). By driving load device **102** by two 3-phase transformer/voltage controller apparatus that produce non-congruent voltage signals and thus combine constructively, load device **102** effectively receives power from two non-competing independent sources, thereby avoiding power system instability that may have occurred had first and second transformer sets **119** and **129** produced in-phase voltage signals.

[0025] When one of first and second transformer sets **119** and **129** malfunctions, and/or no longer provides power to load device **102,** the power originally drawn and provide by the malfunctioning transformer set will be diverted and handled by the other transformer set. The other transformer set will thus be able to provide the same total power to load device **102**, and all other load devices connected to the transformer sets, that was originally provided by the two transformer sets working in tandem. Testing performed on the embodiment of the system shown in **FIG. 1** has shown that in situations where one of the transformer sets malfunctions, power continues to be provided to the load devices without any power interruptions. Although the malfunction of one transformer set may create a momentary power instability as the remaining transformer set attempts to adjust and stabilize its power output, stable power flow to the load devices is achieved within approximately two to five milliseconds. It will also be appreciated that when system **100** has only one transformer set delivering power, the frequency of the voltage signal delivered to the load devices will be approximately half the frequency of the combined signal produced by the tandem operation of first and second transformer sets **119** and **129**.

[0026] As would further be understood by a person skilled in the art, during operation of system **100**, switches **130**, **132**, **134**, and **136** are closed and provide a direct electrical path between the output of voltage controller **116** and **126**, respectively, and load device **102**. When power to load device **102** (and all other connected load devices) is interrupted due to a malfunction of one of first and second transformer sets **119** and **129**, for example, it is necessary to take the malfunctioning transformer set off-line for repair and maintenance purposes to restore

system **100** to normal operation. To restore system **100** to its normal operation, the malfunctioning module is first identified, and subsequently the corresponding transformer set is disconnected from load device **102** and power source **104** by switching off the corresponding switches. The remaining transformer set will, as noted, remain connected in a closed electrical path to load device **102** (and all other load devices connected thereto), and accordingly will continue to provide power to the connected load device(s). Once the malfunctioning transformer set has been repaired, it can be reconnected to the load device(s) by closing the corresponding switches, and restoring the parallel power supply configuration of system **100**.

[0027] **FIG. 2** provides a more detailed illustration of system **100** to power a brushless exciter that in turn creates a magnetic field inside a generator **150**. More particularly, as can be seen in **FIG. 2**, first voltage controller **116** and second voltage controller **126** power brushless exciter **102**, which creates a magnetic field inside generator **150** needed to generate power. The voltage signal generated by generator **150** is transmitted to power-consuming loads (not shown) via power lines **156**. The voltage signals presented by each of voltage controller **116** and **126** are positive polarity oscillating voltages having a frequency of 360 Hz (see first and second signals **142** and **144, FIG. 1**). As previously noted, the resultant signal **146** constituted from the first and second signals **142** and **144** (as shown in **FIG. 1**) is a positive polarity oscillating signal having a frequency of 720 Hz.

[0028] As further shown in **FIG. 2**, coupled to first and second voltage controllers **116** and **126** is a power system stabilizer (PSS) **152**. PSS **152** can be viewed as an additional block of a generator excitation control or Automatic Voltage Regulator (AVR) that can be added to improve the overall power system dynamic performance, especially for the control of electromechanical oscillations. The PSS can thus use auxiliary stabilizing signals such as shaft speed, terminal frequency, and/or power to change the input signal to the AVR. This can enhance small-signal stability performance on a power system network. PSS **152** can thus be understood to extend the angular stability limits of a power system by providing supplemental damping to the oscillation of synchronous machine rotors via the generator excitation. In some systems, this damping is provided by an electric torque that is applied to the rotor(s) and in phase with the speed variation

of the rotor(s). The additional control provided by PSSs can thus be advantageous during line outages, power transfers, and other interruptions. In system **100** shown in **FIG. 2**, PSS **152** probes power lines **156** to detect, among other things, any power fluctuations, and accordingly determines whether any system instability is present in system **100**. Based on information PSS **152** extracts from power lines **156**, PSS **152** generates output control signals that are sent to voltage controllers **116** and **126**, which thereafter make adjustments to the voltage signals produced by them. PSS **152** may be one of the various commercially available PSS, such as Basler Electric PSS-100, or PSS **152** may be implemented as a CPU-based device which can store and execute computer instructions. Optionally, as shown in **FIG. 2**, another controller **154** for providing additional control to the overall stability of system **100** may be added. Such a controller may also be a commercially available controller, such as the TRICON TS 3000, or may also be implemented as a CPU-based device capable of storing and executing computer instructions.

[0029] **FIGS. 3-7** show in yet greater detail the specific implementation features of the system **100** shown generally in **FIG. 1**, and more particularly in **FIG. 2**, including diagrams and schematics detailing the various ports and connections used in a specific implementation of system **100**.

[0030] **FIG. 8** is a schematic diagram showing an exemplary Excitation Drive system retrofit **170** using a system similar to system **100** shown in **FIG. 1**. As shown in **FIG. 8**, the system **170** comprises an Automatic Voltage Regulator (AVR) **172** and a delta-delta transformer **174** coupled to a wye-delta transformer **176** in an electrical parallel configuration. System **170** is implemented in such a way that system **170** is capable of on-line restoration to full system status, without requiring a operating generator system interruption or shutdown. AVR **172** may be any commercially available AVR such as, for example, the Triconex Generator Control system able to provide triple-modular-redundant (TMR) fast acting digital based generator control functionality that includes a fault tolerant redundant set of current sharing exciter drives that may be on-line changeable and maintainable. Such a fault-tolerant feature may allow system **170** to

continue to operate and to control the generator system, if or when any included related system component suddenly fails.

[0031] Coupled to the delta-delta transformer **174** and wye-delta transformer **176** are first and second digitally controlled three-phase full wave controlled rectifier bridges **178** and **180** respectively. Both first and second bridges **178** and **180** may incorporate generator terminal voltage PID controls, which can be switched on to cascade into high gain exciter field current drive PID control loops. System **170** may also operate with modern off-the shelf industrial Power System Stabilizer (PSS) devices that have an adjustment signal scaled for +/- 10 V (DC). Both first and second bridges **178** and **180** utilize a supply (ac) side internal current "input flow" to generate an "output flow" dc current signal for the exciter field current drive. The first and second digitally controlled three-phase full wave controlled rectifier bridges are supplied different (i.e., 30° phase shifted) voltages, which creates a unique control firing trigger pattern region for each one of the twelve total (6 per bridge) combined system set of rectifiers. This carefully created combination of conditions uniquely allows these two drive bridge outputs to easily be combined together into one resulting dc current output, while also allowing each drive bridge to maintain and perform closed loop current control with its own independent PID control contribution. The cascaded generator terminal voltage PID control is utilized as the very fast response system supporting part of the traditional "Automatic Voltage" AVR control mode.

[0032] System **170** is configured to accept either 50 or 60 Hz rated system three-phase instrument sensing signals from generator current transformers (CT's) and potential transformers (PT's). A possible arrangement would have three CT's scaled for a maximum of 5 amperes secondary current signals. A possible arrangement would also have two PT's in an open delta configuration scaled for a nominal 120 V (AC) phase to phase signal.

[0033] **FIG. 9** shows a power system application **200** in which multiple transformers, grouped to pairs of transformer sets are used. A brief description of the nature of the specific application of the embodiment shown follows, but it will be appreciated that the description of a specific power system application is for illustrative purposes only and to facilitate understanding of the operation of the multiple transformer arrangement **201** shown in **FIG. 9**, and in no way is

intended to restrict the type and number of applications and devices in conjunction with which multiple transformer arrangement **201** may be used. Rather, the embodiment of multiple transformer arrangement **201**, and other embodiments of a multiple transformer arrangement as described herein, may be used to provide power to any type and any number of power applications and/or devices, and that such power applications and/or devices may include commercially available machines, devices, and/or systems, as well as custom-made power applications, machines, systems, and/or devices.

[0034] More particularly, shown in **FIG. 9** is a conventional generator **204** which, as is well understood, generates voltage and current through rotational movement of an armature rotating through a magnetic field inside the generator. In the system shown in **FIG. 9**, the magnetic field through which the generator's armature moves is created and sustained using exciter **202**. Exciter **202** is a conventional exciter, such as those manufactured by Toshiba or by Electric Machinery Company, and generates the DC current that is needed to create the magnetic field inside generator **204**. As can be further seen in **FIG. 9**, exciter **202** is powered by the power produced by generator **204**. Particularly, the AC voltage produced by generator **204**, which in **FIG. 9** is shown to be a 3-phase 24 KV, is directed to a first 3-phase transformer **210**, and to a 3-phase zig-zag transformer **220**. Transformers **210** and **220**, and more particularly transformer arrangement **201**, draw just enough power from generator **204** as is needed to power exciter **202**. However, the bulk of the power produced by generator **204** is directed to power-consuming loads (not shown) via transformer **206** and power lines **208**. In the specific example of system **200**, transformer **206** transforms the generator's **204** voltage level of 24 KV to 375 KV.

[0035] As further shown in **FIG. 9**, first and second 3-phase transformers **210** and **220** are coupled to first and second transformer groups **212** and **222** respectively. Each of transformer groups **212** and **222** comprises a delta-delta transformer and a DC drive, connected in parallel to a wye-delta transformer and another DC drive. As will become apparent below, additional transformer groups and/or transformers may be added to the system so long that the transformer groups and/or transformers that are connected to the load(s) (in this case, exciter **202**) do not

compete with each other for control of the power source(s) in a way that would render the power system unstable.

[0036] In the **FIG. 9** embodiment, both first and second transformer groups **212** and **222** are similar in construction and manner of operation to the transformer arrangement of system **100** in **FIG. 1**. With reference to first transformer group **212**, as can be seen, the inputs of the first delta-delta transformer **214** and first wye-delta transformer **215** are coupled, via a switch **218**, to the first 3-phase transformer **210** which transforms the 3-phase voltage power produced by generator **204** to a voltage level for transformer group **212**. In this example, first 3-phase transformer **210** transforms the 3-phase 24KV voltage level produced by generator **204** to a 3-phase 480V voltage level. Thus, since first 3-phase transformer **210** transforms the voltage level produced by generator **204**, transformers **214** and **215** do not change the voltage level of the voltage they receive as input, but rather are used, in this case, to produce a voltage signal that has a frequency of 720 Hz. If transformer group **212** malfunctions, or otherwise has to be taken off-line, switch **218** can be put into its open position, thereby electrically disconnecting first transformer group **212** from generator **204**. Optionally, additional switches (not shown) may be connected to the input or output of either one of first delta-delta or first wye-delta transformers **214** or **215** so that if one of the transformers **214** or **215** malfunctions, only the malfunctioning transformer would have to be disconnected from the rest of the system **200**.

[0037] Coupled to the output each of first transformers **214** and **215** are first and second voltage controllers **216** and **217** respectively, which, in a manner similar to the operation of first and second voltage controllers **116** and **126** of system **100** in **FIG. 1**, control and rectify the voltage they receive as input from first and second transformers **214** and **215**. The first and second voltage controllers **216** and **217** may be any of the various commercially available voltage controllers, including, for example, the Eurotherm 590+ driver, or alternatively, the voltage controllers may be implemented using a CPU-based device as was described in reference to first and second voltage controllers **116** and **126** of system **100** in **FIG. 1**. Since in the specific example illustrated in **FIG. 9** the first and second voltage controllers are intended primarily to produce a DC voltage (or an approximation thereof), in **FIG. 9** voltage controllers **216** and **217**

have been labeled as DC Drive 1B and DC Drive 1A respectively. However, it will be clear to the person versed in the art that first and second voltage controllers **216** and **217** need not produce only DC voltage but may perform other functions and may produce other voltage signal forms as would be required by the particular application in which the transformer arrangement described herein is to be used. Optionally, other voltage and/or power control apparatus, such as power conditioners (not shown), may be coupled to either to the first and second transformers **214** and **215**, and/or to first and second voltage controllers **216** and **217**.

[0038] As was previously explained in relation to system **100** shown in **FIG. 1**, the output of a wye-delta transformer is phase shifted by 30° with respect to a 3-phase AC input voltage signal. The delta-delta transformer, on the other hand, does not result in a phase shift of the transformer's output with respect to the input voltage signal. As a result, the output of the voltage controller **217**, will be phase-shifted by 30° with respect to the output of voltage controller **216**. Since in the particular example of the application shown in **FIG. 9** both voltage controllers **216** and **217** produce voltage signals having a positive polarity, and having a frequency of 360 Hz, combining the outputs of voltage controllers **216** and **217** will result in a positive polarity voltage signal having a frequency of 720 Hz.

[0039] In the **FIG. 9** embodiment, second transformer group **222** is similar in construction and manner of operation to first transformer group **212**, with the exception that second transformer group **222** is coupled to a 3-phase zig-zag transformer that phase shifts the voltage produced by generator **204** by 15°. Consequently, the voltage produced by the output of the delta-delta transformer **224** will be phase shifted by 15° with respect to the voltage signal of generator **204**, and the output of the wye-delta transformer **225** will be phase shifted by 45° with respect to the voltage signal of generator **204** (the 15° shift caused by second 3-phase transformer **220**, plus the 30° shift caused by a wye-delta transformer). By extension, the combined output of third and fourth voltage controllers **226** and **227** will be a positive polarity voltage signal having a frequency of 720 Hz, which is phase-shifted by 15° with respect to the output of first transformer group **212**. Thus, combining the two non-congruent or out-of phase 720 Hz voltage signals produced by first and second transformer groups **212** and **222** respectively will result in a

voltage signals that has twice the number of ripples, or cycles, as any one of the signals produced by first and second transformer groups **212** and **222** individually, thereby resulting in a single voltage signal having a frequency of 1440 Hz.

[0040] **FIG. 9** further shows that first 3-phase transformer **210** and zig-zag second 3-phase transformer **220** are coupled to select switch **240**, the output of which is, in turn, coupled to 3-phase full wave rectifying diode bridge **242**. Additionally, also coupled to the input of exciter **202** is a DC power source **244** connected to field flashing circuitry **246**. As will be appreciated, since the exciter **202** is ordinarily powered by generator **204**, when generator **204** is idle and has to be started, exciter **202** may initially be powered by DC power source **244**. Once the exciter begins operating, thereby creating a magnetic field inside generator **204** which in turn enables generator **204** to produce power that can be partly used to power exciter **202**, the DC power source **244** field flashing circuit **246** may be disconnected from exciter **202**.

[0041] In operation, first and second transformer groups **212** and **222** each receive a voltage signal from first and second 3-phase transformers **210** and **220** respectively, and produce a half rectified or fully rectified voltage signals. Due to the phase shift caused by zig-zag transformer **220**, the output voltage signal of second transformer group **222** will be phase-shifted by 15°, and consequently, since the two output voltage signals produced by first and second transformer groups **212** and **222** will not be congruent, the first and second transformers groups **212** and **222** will not compete with each other for control of system **200**. Rather, first and second transformer groups **212** and **222** will cooperate with each other in the sense that the two output voltage signals produced by first and second transformer groups **212** and **222** and presented at the input to exciter **202** will result in a single voltage signal having a frequency that is twice the frequency of each of the individual voltage signals produced by first and second transformer groups **212** and **222**. Subsequently, if one of first and second transformer groups **212** and **222** malfunctions and/or is taken off line, the remaining transformer group will continue to supply exciter **202** with a voltage signal having half the frequency of the that the combined voltage signal, cooperatively generated by first and second transformer groups **212** and **222**. It will be appreciated that by using a total of four transformers, if one transformer group is taken off line, one transformer

group, having two transformers, will be able to deliver the power needed to operate the load device(s). By contrast, when using a two transformer arrangement, as was done in system **100** of **FIG. 1**, a malfunction of a single transformer would leave only one transformer to handle the power requirements of the load device(s) connected to the system. Furthermore, having two out of four functioning transformers in system **200** may result in a signal that is a good approximation of a DC signal.

[0042] As will be further appreciated, transformer arrangement **201** may be implemented using additional transformer groups comprising, for example, a delta-delta transformer placed in parallel to a wye-delta transformer. Such additional transformer groups could be coupled to additional phase-shifting transformers that would cause the phase of the resultant voltage signals produced by such additional transformer groups to be non-congruent with the voltage signals produced by other transformer groups. Consequently, by having multiple transformer groups produce voltage signals that are out of phase with respect to each other, the resultant signal presented to the power consuming loads would have a frequency relating or approximating the sum of the frequencies of the voltage signals produced by the individual transformer groups. Furthermore, the addition of transformer groups, or even individual transformers, will provide the system with increased redundancy to improve robustness. Also, by adding more transformer groups, or individual transformers, and coupling such transformers to voltage controllers that may perform rectifying and control functions, the resultant voltage signal presented to the power-consuming loads, and having a frequency related to the sum of the individual frequencies of the voltage signals produced by the individual transformers and transformer groups, may more closely approximate a DC voltage signal, and may allow a more efficient operation of power consuming devices, such as exciters, which generally require a DC voltage for optimal operation.

[0043] It will also be appreciated that an overall control module (not shown) may be added to system **100** and/or system **200** to control the various performance features and desired configurations of system **200**. Such a control module could be implemented as a CPU-based device capable of receiving, storing and executing computer instructions, and having peripheral modules for otherwise receiving and sending data and information. Accordingly, the methods

and systems described herein can include a microprocessor having instructions for selecting, enabling, connecting, and/or switching the various transformers and/or transformer groups, and/or to allow the generator to be driven based on an output from the various transformers and/or transformer groups. In one configuration, the instructions can allow a load-sharing configuration to allow for stable operation through, for example, otherwise unstable conditions such as, for example, a power transient. In some embodiments, the instructions can allow the generator to be driven based on outputs from the first and second transformers operating in a parallel configuration, such that outputs from the first and second transformers can be combined to drive the generator.

[0044] The methods and systems described herein are not limited to a particular hardware or software configuration, and may find applicability in many computing or processing environments. The methods and systems can be implemented in hardware, or a combination of hardware and software, and/or can be implemented from commercially available modules applications and devices. Where the implementation of the systems and methods described herein is at least partly based on use of microprocessors, the methods and systems can be implemented in one or more computer programs, where a computer program can be understood to include one or more processor executable instructions. The computer program(s) can execute on one or more programmable processors, and can be stored on one or more storage medium readable by the processor (including volatile and non-volatile memory and/or storage elements), one or more input devices, and/or one or more output devices. The processor thus can access one or more input devices to obtain input data, and can access one or more output devices to communicate output data. The input and/or output devices can include one or more of the following: Random Access Memory (RAM), Redundant Array of Independent Disks (RAID), floppy drive, CD, DVD, magnetic disk, internal hard drive, external hard drive, memory stick, or other storage device capable of being accessed by a processor as provided herein, where such aforementioned examples are not exhaustive, and are for illustration and not limitation.

[0045] The computer program(s) can be implemented using one or more high level procedural or object-oriented programming languages to communicate with a computer system;

however, the program(s) can be implemented in assembly or machine language, if desired. The language can be compiled or interpreted.

[0046] The device(s) or computer systems that integrate with the processor(s) can include, for example, a personal computer(s), workstation (e.g., Sun, HP), personal digital assistant (PDA), handheld device such as cellular telephone, laptop, handheld, or another device capable of being integrated with a processor(s) that can operate as provided herein. Accordingly, the devices provided herein are not exhaustive and are provided for illustration and not limitation.

[0047] References to "a microprocessor" and "a processor", or "the microprocessor" and "the processor," can be understood to include one or more microprocessors that can communicate in a stand-alone and/or a distributed environment(s), and can thus can be configured to communicate via wired or wireless communications with other processors, where such one or more processor can be configured to operate on one or more processor-controlled devices that can be similar or different devices. Furthermore, references to memory, unless otherwise specified, can include one or more processor-readable and accessible memory elements and/or components that can be internal to the processor-controlled device, external to the processor-controlled device, and can be accessed via a wired or wireless network using a variety of communications protocols, and unless otherwise specified, can be arranged to include a combination of external and internal memory devices, where such memory can be contiguous and/or partitioned based on the application. Accordingly, references to a database can be understood to include one or more memory associations, where such references can include commercially available database products (e.g., SQL, Informix, Oracle) and also proprietary databases, and may also include other structures for associating memory such as links, queues, graphs, trees, with such structures provided for illustration and not limitation.

[0048] Although the methods and systems have been described relative to specific embodiments thereof, they are not so limited. Obviously many modifications and variations may become apparent in light of the above teachings.

[0049] Many additional changes in the details, materials, and arrangement of parts, herein described and illustrated, can be made by those skilled in the art. Accordingly, it will be

understood that the following claims are not to be limited to the embodiments disclosed herein, can include practices otherwise than specifically described, and are to be interpreted as broadly as allowed under the law.